FIRST STEPS IN ESTIMATING THE TOTAL ECONOMIC VALUE FOR LANDSLIDE HAZARD MITIGATION ON NATIONAL FOREST SYSTEM LANDS

Thomas E. Koler[1], John B. Loomis[2] & John C. Bergstrom[3]

[1] *El Dorado National Forest (e-mail: tkoler@fs.fed.us)*
[2] *Colorado State University (e-mail: John.Loomis@colostate.edu)*
[3] *University of Georgia (e-mail: jberg@uga.edu)*

Abstract: Recent research using an economic valuation method indicates that landslide mitigation programs have positive benefits to American society as measured by citizens' willingness to contribute money to support such programs. This research also indicates that U.S. National Forest Service district rangers assign positive benefits to landslide mitigation programs as measured by their willingness to allocate a portion of management budgets to such programs. The general public is not risk-averse in having business decisions completed by federal managers and these line officers are willing to take measured risk in managing the large landslide natural resources. An individual or group that is risk-averse will pay to reduce a risk. In some cases of landslide management the public or manager is unwilling to assume any risk associated in mitigating the landslide hazard due to the perceived costs. A result is the avoidance of any landslide management and the public lands are set aside, for example, as wilderness or habitat protection areas. Therefore the economic values of both the public and agency managers are important in understanding the landslide economics.

In order to evaluate the landslide economics, an accurate landslide inventory must be completed to perform a benefit cost analysis of the different types of landslide identification and mitigation methods. With the advent of Light Detection and Ranging (LiDAR) technology the accuracy of a landslide inventory increases due to the ability of LiDAR to "remove" vegetation from digital elevation models used in the inventory process. This new technology is popular amongst landslide scientists and decision-makers, but no work has been completed to assess its economic viability through a benefit-cost analysis.

Research is being completed in a small watershed to test the reliability of LiDAR for identifying landslides associated with previous timber harvesting, mining and other ground disturbance activities. An evaluation can then be completed for the net public benefits (public benefits minus the cost of LiDAR) and net agency returns. In this benefit-cost analysis, a computation of the net public returns or value of LiDAR technology will be compared to the general public benefits. The general public benefits are estimated from the economic valuation survey results. These benefits are then compared to the agency costs of implementing this technology. Likewise a computation is made of the net agency returns or value of LiDAR technology. This is done by comparing the ranger-perceived benefits of this technology to the actual costs of implementation. These comparisons will be made on a per landslide acre basis or other units of measure.

INTRODUCTION

The objectives of this study were 1) to evaluate the effectiveness of Light Detection and Ranging technology for identifying the location of geological hazards within a watershed; and 2) to evaluate the total economic value (TEV) of applying this technology.

Light Detection and Ranging (LiDAR) technology has been available since the mid-1990s and involves three measuring devices that are attached to an aircraft. These are a GPS unit that records the aircraft's position every 0.5 second; a high-accuracy Inertial Reference System that records the pitch, roll and heading of the aircraft at a rate of 200 times per second; and a pulse laser that emits a discrete laser beam aimed at the ground for measuring the distance between the aircraft and the vegetation canopy (first return data) and the bare ground (last return data). Algorithms are applied to tease out additional data such as the canopy structure and subtleties of ground disturbances (Haneberg, 2005). Several researchers have described the application of LiDAR in mapping geologic hazards and although it is not perfect it is currently very popular (e.g., McKean and Roering, 2004; Schulz, 2004; and, Sever, 2003).

Landslide economic studies have been focused on direct and indirect costs associated with consequences as defined in the geological literature on landslide risk management (e.g., Schuster, 1978; Fleming and Taylor, 1980; Schuster, 1996; and Roberds, 2005). Landslide economics and a probabilistic approach in the hazard mapping was initially explored as a viable means of assessing economic values by Bernknopf et al. (1988). Risk is defined by Wu et al. (1996) as the function of landslide hazard probability multiplied by the landslide consequences. Leighton (1976) defines direct and indirect costs as: "Direct costs include destruction or damage to structures and other improvements, loss of damage to lands, and (or) reestablishment of structures, other improvements, and land as nearly as possible to the same condition and degree of usefulness as prior to the landslide. Indirect costs include the following: relocation of buildings and roadways, measures to prevent or mitigate additional landslide damage, secondary physical effects such as flooding and adverse effects on water quality in streams and irrigation facilities, measures to prevent secondary effects, decrease in agricultural or industrial production, decrease in market value of affected properties, tax loss due to decrease in appraised value, and measures to protect health and safety of the public. Indirect costs can also include time lost from work and associated effects of decreased earnings: the loss of purchase power which is passed on through the economy, possible foreclosure of mortgages and other loans, depletion of savings accounts, and lack of funds for insurance or investment plans. Obviously, many of these costs are seldom if ever determined, and damage assessments tend to be conservatively low." Leighton also identifies the importance of separating economic values for both direct and indirect landslide costs: "The greatest value of separating direct and indirect costs may be to help insure that all costs related to landslides are identified." Direct costs are therefore tangible and easily estimated or measured in dollars. Indirect costs are more difficult and as Schuster (1978) points out: "Indirect costs of landslides are difficult to evaluate, but they may be larger than the direct costs."

The direct and indirect costs associated with landslide consequences can be identified through an "event tree" analysis (Roberds, 2005). In this analysis the possible consequences of events after the landslide hazard occurs are identified. Conversely, Roberds points out that "fault tree" analyses provide information on the various ways that a failure can occur and commonly used in evaluating landslide hazards. The "fault tree" analyses provide output showing initiation of landslide movement (i.e., landslide hazard probability) and the "event tree" analysis provides input on the consequence costs (both direct and indirect). The consequences can then be combined into a single measure for decision-makers to apply in selecting alternatives for landslide mitigation. Roberds describes the "tradeoffs" amongst the various consequences as being expressed in terms of willingness-to-pay (WTP) to change the consequence. Thereby in this form the manager makes his/her decision based on a landslide risk analysis in which a fault tree provides the hazard probability for a landslide event to occur and the event tree evaluates the possible consequences from this event. The tradeoffs between decisions are measured in terms of WTP (Roberds, 2005).

In this article we suggest that another model can be applied in evaluating the economics of landslide risks that also applies willingness-to-pay analysis. This method includes the total economic value (TEV) associated with this decision-making process and thereby provides a solution to finding an economic value for both direct and indirect costs. This model has been successfully applied in recent landslide risk management research (Koler, 2004 and 2005) indicating that economic values associated with landslides can be estimated within a TEV analysis. This is especially important with the emphasis placed in ecosystem management by the American public and policy makers (Koler, 2006).

ECOSYSTEM VALUES AND TOTAL ECONOMIC VALUE

The economist's primary role is to identify the ecosystem management benefits arising from landslide risk management for which economic valuation is appropriate and feasible; and, thereby estimate the economic values for these benefits as accurately as possible. The overall goal of economic valuation of ecosystem management is to measure the total economic value of natural resources affected by management actions.

Economists estimating the total economic value (TEV) of natural resources, including avoiding damage to these natural resources from landslides, divide them into two broad categories (Bergstrom and Loomis, 1999). When an agent is actively using a natural resource the value derived is referred to as the active-use value (AUV). In the AUV are compartment activities within which values are generated as on- or off-site, and consumptive or non-consumptive. The other category is the passive-use value (PUV) and it is derived from using a resource in a non-consumptive and non-rival manner. Although it is difficult to compare the direct/indirect cost analysis with the TEV analysis, a generality between the two can be made: passive use costs appear to include some indirect costs but not direct costs.

The passive-use value (PUV) reflects what economists refer to as public goods. These are non-consumptive and non-rival in the sense that a person's passive use value does not preclude someone else from obtaining enjoyment from their PUV. Passive use values are nonexclusive in the sense that no one can be denied the opportunity to think about or obtain satisfaction from knowing that a particular ecosystem exists. Private goods are different from public goods in that private goods generate rival and exclusive values.

In the landslide economic literature cited above the definition of public and private goods defers slightly from the definition presently accepted by applied economists. For example, Schuster (1996) defines public costs as: "…those that must be met by government agencies; all others are private costs." And for private costs Schuster defines them as: "…consist[ing] mainly of damage to real estate and structures, either private homes or industrial facilities." In a total economic value (TEV) analysis the costs associated with public goods may be met by government agencies who serve the American public in meeting their passive-use value (PUV). However, private property owners in a TEV analysis may also need to meet the costs associated with public goods – one example would be the industrial timberland manager presented with the dilemma of downstream effects from an active landslide on the property that is depositing sediment in a threatened aquatic habitat several miles downstream. Therefore the comparison between the public and private goods presented by Schuster and those within a TEV analysis is akin to the proverbial comparison between oranges and apples as shown in Table 1 below which presents a comparison between the traditional USGS landslide economic valuation approach and the new Total Economic approach. For the rest of this article the application of public and private goods follows the TEV approach.

Table 1. Comparison of costs between the USGS and Total Economic Value approaches.

	USGS Landslide Cost Variables		**Total Economic Value Cost Variables**		
	Direct Costs	**Indirect Costs**	**Active Use Costs**		**Passive Use Costs***
Examples			**On-Site**	**Off-Site**	
Highways and roads	X		X	X	
Real property	X	X	X	X	
Loss of resource revenue (agricultural, industrial, tourist, etc.)		X	X	X	
Reduced real estate values threatened by landslides		X	X	X	
Adverse effects on water quality		X	X	X	X
Big game hunting within the landslide prone area		X	X†		
Burning firewood obtained within the landslide prone area to heat one's home.				X†	
Wildlife photography within the landslide prone area.			X‡		
Swimming in a lake with at least one source of water is from the landslide prone area.				X‡	
Knowing that a particular panorama view exists within the landslide prone area.					X
Watching or listening to wildlife tapes of animals known to be located in a landslide-prone area.				X‡	

* The term passive use was first used in the ruling by the United States Court of Appeals for the District of Columbia v. Department of the Interior, 880 F.2d 432 (D.C. Cir. 1989). The value derived from passive use has been referred to as nonuse value, existence value, and bequest value (Carson et al., 1997). All passive values are non-consumptive.

†This is a consumptive value in the sense that there is competition for this value and it is consumed.

‡This is a non-consumptive value in the sense that the resources are not consumed.

Willingness-to-Pay

Roberds (2005) defines the willingness-to-pay (WTP) as "For decision making, it is often convenient to combine the different types of consequences (e.g., financial costs, loss of services, etc.) into a single measure. This requires the assessment of "tradeoffs" amongst the various types of consequences, typically expressed in terms of equivalent costs (or willingness to pay to change the consequence)." An accepted method for estimating WTP in a total economic value framework, including the management of landslides, is the contingent valuation method (CVM) in which a survey instrument is constructed that meets CVM protocol as described by Mitchell and Carson (1989) as well as other economic researchers (e.g., Haab and McConnell, 2002). The protocol provides direction in minimizing bias survey data. Upon completion of the survey, data are evaluated through a multivariate logistic regression in which the mean willingness-to-pay (WTP) is calculated from the parameters that influence the decision to pay (e.g., water quality, panoramic views, etc.). With mean WTP estimated from the survey data the American publics' benefits from the management of landslide prone areas as well as the net return derived through the land managers' decision making can be assessed.

Contingent Valuation Method

Loomis (2002) describes the contingent valuation method (CVM) as the following. "The contingent valuation method is a survey technique that constructs a hypothetical market or referenda to measure willingness-to-pay or accept compensation for different levels of non-marketed natural and environmental resources. The method involves in-person or telephone interviews or a mail questionnaire. The CVM not only is capable of measuring the value of outdoor recreation under alternative levels of wildlife and fish abundance, crowding, instream flow, and so on, but is the only method currently available to measure other resource values, such as the benefits that the general public receives from the continued existence and services of unique natural environments, species, or entire ecosystems." The CVM has undergone a great deal of scrutiny over the past decade and is today considered to be a well-tested method for estimating the economic value of environmental goods and services (Haab and McConnell, 2002) and recognized as such by the U.S. Department of Commerce. The steps in coming to this conclusion have been incremental during the last decade (e.g., Smith 1996; Ready et al., 1996; and Carson, 1989) as researchers showed that CVM is reliable when applying discrete survey questions. There are still studies that claiming hypothetical bias in CVM unless steps like Cheap Talk or Uncertainty Calibration are used.

In the seminal work by Mitchell and Carson (1989) several biases were explained as creating problems with the CVM and these authors proposed the referendum approach as being less troublesome than other approaches such as elicitation, bidding, payment card, and take-it-or-leave techniques. The referendum approach is today recognized as a preferred method (Champ et al., 2002) and the referendum approach was recommended by the blue ribbon panel on CVM chaired by two Nobel Laureate economists (Arrow et al. 1993).

Previous research applying the CVM showed that the American society have positive benefits of landslide mitigation programs as measured by their willingness to contribute money to support such programs (Koler, 2004 and 2005). This research also indicates that U.S. National Forest Service district rangers assign positive benefits to landslide mitigation programs as measured by their willingness to allocate a portion of management budgets to such programs. The general public is not risk-averse in having business decisions completed by federal managers and these line officers are willing to take measured risk in managing the large landslide natural resources.

Benefit-Cost Analysis

To complete a benefit cost analysis an accurate landslide inventory must be completed. With the advent of Light Detection and Ranging (LiDAR) technology the accuracy of a landslide inventory increases due to the ability of LiDAR to "remove" vegetation from digital elevation models used in the inventory process (Haneberg, 2005). Our study is being completed in a small watershed to test the reliability of LiDAR for identifying landslides associated with previous timber harvesting, mining and other ground disturbance activities. An evaluation can then be completed for the net public benefits (public benefits minus the cost of LiDAR) and net agency returns. In this benefit-cost analysis, a computation of the net public returns or value of LiDAR technology will be compared to the general public benefits. The general public benefits are estimated from the total economic value survey results. These benefits are then compared to the agency costs of implementing this technology. Likewise a computation is made of the net agency returns or value of LiDAR technology. This is done by comparing the ranger-perceived benefits of this technology to the actual costs of implementation. These comparisons will be made on a per landslide acre basis or other units of measure.

PROJECT STUDY AREA

The project study area is located within the El Dorado National Forest in the central Sierra Nevada Mountain Range approximately 100 miles west from the Nevada/California boundary as shown in Figure 1. The study watershed is in the historical "mother lode" area of the mid-19th century California gold rush. The Otter Creek watershed is approximately 10 square miles in size and flows into the Rubicon River which in turn flows into the Middle Fork of the American River, draining into the Sacramento River and then into the San Francisco Bay. Downstream effects, therefore, can include landslide consequences that affect natural resource values within the greater Bay area.

Otter Creek was identified as a "pilot" project to test the application of LiDAR technology for locating geological hazards within the watershed. The geologic hazards include abandoned mine features such as shafts, pits and adits, as well as landslides. Potential consequences from these hazards include public safety (loss of limb or life) as well as deleterious effects to natural resource values such as water quality, bat habitat, aquatic habitat, heritage (i.e., prehistory Native American sites, mining and homesteading sites), and recreation. These resource values as well as others will be identified for the contingent valuation method through a focus group process in constructing the survey instrument.

Underlying the study area are metamorphic rocks of the Devonian-Ordovician Shoo Fly Complex overlain by volcanic rocks of the Tertiary Valley Springs and Merhton Formations (Coyle, 1993; and, Harden, 1998). The younger bedrock units were deposited as volcaniclastic flows along the Tertiary valley floors to subsequently form an inverse topography following tectonic uplift of the Sierra Nevada Mountain Range. Today the volcanic units are found on ridge tops. Local anecdotal information states that most landslides in this area are commonly found along the contact boundary between the Tertiary formations with the underlying Paleozoic Shoo Fly Complex. Landslide initiation sites are commonly associated within areas where increase spring discharge occurs during wet water years (Coyle, 1993). This anecdotal information remains untested and at best hypothetical.

Figure 1. Location map for the Otter Creek watershed study area.

CURRENT FINDINGS

Previous landslide hazard studies in the Otter Creek area were completed by stereo pair aerial photographic interpretation. Limited field verification of this remote sensing work was completed on a project by project basis. LiDAR data were collected so that mapping products such as shaded relief and topographic maps have a 1 meter resolution in the horizontal and vertical axes. The landslide inventory resulting from these two methods are provided in Table 2.

Table 2. Otter Creek Landslide Inventory Results from stereo pair aerial photographic interpretation and LiDAR map products.

Stereo Pair Air Photo Landslide Inventory				**LiDAR Landslide Inventory**			
Landslides	**Debris Flows**	**Debris Slides**	**Earth Flows**	**Landslides**	**Debris Flows**	**Debris Slides**	**Debris Slides – Debris Flows**
12	3	6	1	16	64	40	15

These two inventories indicate the viability of LiDAR in collecting landslide inventories that are more complete than the traditional approach of using stereo pair aerial photographs. This disparity is due to canopy coverage of landslides preventing the analyst to “see through” the canopy where potential landslides may be located (Robison et al., 1999). The geological literature is replete with LiDAR studies and Haneberg (2005) provides a good summary of this work. It is important to note that LiDAR is not the only technology being applied in collecting landslide inventories. A variety of technologies using thermal, radar, and spectral data collection have also been successful and inexpensive. LiDAR was chosen based on its low unit cost of approximately $1.50/acre for watershed scale projects (i.e., 1:24,000 scale). These watershed projects are typically several tens of thousands of acres in size.

Locating abandoned mine features with LiDAR was inconsistent in this pilot study because of scale problems associated with the resolution of the data collection. Some shafts were easily seen in the LiDAR data whereas most were not obvious. If LiDAR data were collected with a higher resolution of less than 1 meter, it may be possible to locate these hazards. Additional work will need to be completed to determine if this is possible.

Locating landslides by LiDAR in this study area was uncomplicated because of the absence of vegetative cover. In the process of completing the inventory Koler asked non-geologists to "give it a best guess" in using a shaded relief map to locate landslides. Several decision-makers were amazed at the clarity of the data and ease in drawing landslide boundaries – LiDAR basically sold itself to these individuals. The landslide inventory was completed by one analyst to keep a consistency in the process. Ten percent of the inventory was field verified and a total of 135 landslides were inventoried in comparison to the old inventory using the traditional stereo pair aerial photographic interpretation which had 22 landslides.

NEXT STEPS

At this point we have evaluated the feasibility of applying the LiDAR technology in identifying geological hazards on the disturbed ground in the study area. It is apparent that abandoned mine features such as shafts and pits may still be difficult to find with LiDAR at the 1 meter resolution. The landslide inventory collection, however, was more successful as previously noted above.

The next steps include the following: (1) testing of the survey instruments with focus groups; (2) complete the contingent valuation method survey; (3) statistically analyze the survey data using multivariate logistic regression; (4) estimate the net public benefits (public benefits minus the LiDAR cost) and net agency returns; (5) complete a benefit-cost analysis comparing the economic value of LiDAR technology to the general public benefits; (6) compare the benefits in step 5 with the agency costs of implementing this technology; (7) in a similar fashion compute the net agency returns or value of the LiDAR technology; and, (8) make these comparisons on a per landslide acre basis or other suitable units of measure.

CONCLUSIONS

Over the last three decades several geoscientists have made an attempt at estimating the economic costs associated with landslide movement. Identifying and characterizing landslides is an expensive proposition. Therefore in landslide studies there are two economic challenges: the landslide technology economics and the total economic value of landslides.

Recent efforts in applying Light Detection and Ranging (LiDAR) technology are showing promising advances in identifying and characterizing landslides at a cost of approximately $1.50/acre. The advantages of using this technology are the high resolution and ease of use of the remote-sensing products. Engineers and geologists are frequently easy converts to this technology because of the highly accurate digital elevation models it produces and even sceptical decision-makers are able to identify landslides in LiDAR products.

As new technology developed, landslide researchers and professionals have been able to compile more complete landslide inventories. Parallel to this work has been the question about the economics of landslides, especially the economics of direct and indirect costs. Recent work by applied economists shows promising results in estimating the total economic value of landslides with the contingent valuation method for projects, proposals, and policy actions. Research by Koler (2004 and 2005) demonstrates the viability in viewing landslide risk management in a total economic value approach as measured by the positive value associated with this decision-making process by the American public and the managers making the decisions. This work has been extended into evaluating the benefit-cost relationships in using LiDAR technology in identifying and characterizing geologic hazards such as landslides and abandoned mine features that are hidden by canopy coverage. This on-going study is within the Otter Creek drainage located within the mother lode country of the California Sierra Nevada Mountain Range where heavy mining occurred during and after the California gold rush. Initial results indicate that LiDAR technology, with data collection at a 1 meter resolution, is inconsistent for locating abandoned mine features. Landslide identification and characterization with LiDAR data, however, are more complete than the traditional stereo-pair aerial photographic analyses. The next phase of this research will be the benefit-cost analyses for applying this technology. Comparisons between American publics' and federal managers' economic values will then be completed on a per landslide acre basis.

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Corresponding author: Dr Thomas E. Koler, El Dorado National Forest, 100 Forni Road, Placerville, California, 95667, USA. Tel: +1 530 295 5642. Email: tkoler@fs.fed.us.

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